Collisions in Two Dimensions

"In the field of observation, chance only favors those minds which have been prepared"

L. Pasteur

OBJECTIVES

To qualitatively and quantitatively examine some collisions.

THEORY

Much of our knowledge of atoms and nuclei and all of our knowledge of elementary particles is derived from observations of carefully arranged collisions. The basic sequence of a collision is shown in Fig. 1, along with a convenient set of reference axes. The goal of a collision experiment is to find out how the particles interact during the collision by measuring the masses and velocities of the particles before and after the collision. In the case of microscopic objects, we often do not have direct access to what the particles do during the collision because the lengths and times involved are too small for observation, so there is no more direct way to obtain this information. In this experiment you will study several simple collisions between macroscopic objects to gain some understanding of how these experiments work.

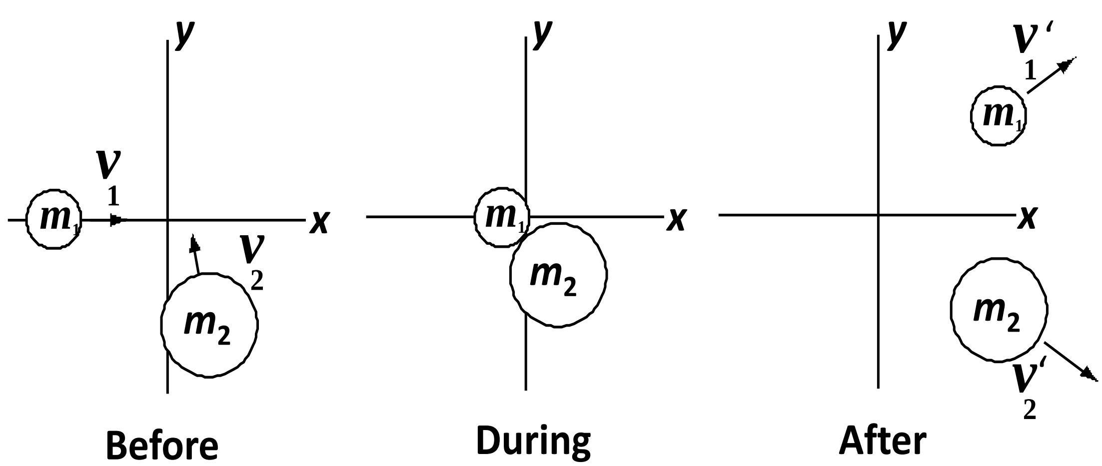

Fig. 1 A collision sequence

In many cases the conservation laws restrict, but do not totally determine, the results of a collision. For example, if the force between m_1 and m_2 is the only force which can change their motion, then momentum will be conserved in the system consisting of m_1 and m_2. We can write the equations for conservation of momentum as

$$m_1 v_{1x} + m_2 v_{2x} = m_1 v'_{1x} + m_2 v'_{2x} \tag{1}$$

and

$$m_1 v_{1y} + m_2 v_{2y} = m_1 v'_{1y} + m_2 v'_{2y} \tag{2}$$

where the primed velocities are after the collision and the unprimed are before. **<u>These equations assert that the x and y momentum components must both be independently conserved regardless of what happens during the actual collision.</u>** Our air table reduces the frictional forces in the *x-y* plane nearly to zero, so we would expect Eq. 1 and 2 to hold for our experiment.

It may also happen that the translational kinetic energy remains constant during the collision, so that

$$\tfrac{1}{2} m_1 (v_1)^2 + \tfrac{1}{2} m_2 (v_2)^2 = \tfrac{1}{2} m_1 (v_1')^2 + \tfrac{1}{2} m_2 (v_2')^2 \tag{3}$$

If this equation is obeyed, the collision is said to be elastic, otherwise it is inelastic. **<u>Since we do not know much about what happens when two sliders hit each other, we will have to discover experimentally whether our collisions are elastic or inelastic.</u>**

For a collision in two dimensions with known starting conditions there are four unknown velocity components after the collision. Eqs. 1, 2 and 3 supply at most three restrictions on these velocities and in fact, only two if the collision is not known to be elastic. The final velocities must, therefore, be determined by the details of the forces acting during the collision. By measuring the final velocities for various initial conditions one can learn about the interaction force between the particles, at least in principle. During the course of the experiment you will see qualitatively how this works.

EXPERIMENTAL PROCEDURE

The colliding masses are round plastic pieces that are supported on a cushion of air. The air cushion greatly reduces friction between the slider and the surface, and leveling the air table eliminates the influence of gravity, so the only remaining forces are between the colliding objects. **<u>Note that the momentum of the colliding masses will be conserved only</u>**

<u>if the air table is level.</u> A video camera is positioned above the air table surface to record the collisions for analysis using LoggerPro.

The air table system is somewhat delicate, so there are some precautions you must be aware of. **<u>Never slide anything on the surface of the air table when the air flow is off.</u>** This will damage the surface, and may plug the small holes. You should also handle the sliders carefully to avoid nicks and deep scratches which would increase the sliding friction.

Before trying to make observations you must level the air table. Turn on the air supply to the table, set a slider on the surface and observe the direction of motion at several places on the table. Adjust the three legs of the air table so that the slider's motion is minimized at any point. **<u>Note that even when the air table is level, the slider will move around because the surface is not exactly flat and because of air currents in the room, but there should be no consistent direction of motion for the slider at any point on the table when the air table is level.</u>**

<u>The first part of your work will be qualitative.</u> You have two types of plain sliders available, differing in mass. Set up eight different collision combinations:

1. a head-on collision with one light slider as the moving projectile and the other light slider as the stationary target.
2. a near-miss collision (Near-miss collision means after the two sliders collide, they should move in directions that are NOT parallel or antiparallel to the direction of their initial velocities.) with one light slider as the moving projectile and the other light slider as the stationary target.
3. a near-miss collision with both light sliders initially moving toward each other.
4. a head-on collision with one light slider as the moving projectile and the heavy slider as the stationary target.
5. a near-miss collision with one light slider as the moving projectile and the heavy slider as the stationary target.
6. a near-miss collision with one light slider and one heavy slider initially moving toward each other.
7. a head-on collision with the heavy slider as the moving projectile and one light slider as the stationary target.
8. a near-miss collision with the heavy slider as the moving projectile and one light slider as the stationary target.

<u>Best results will be obtained if the collisions are gentle.</u> DO NOT treat the sliders like the pucks of an air hockey game. Hard collisions cause the edges of the sliders to hit the surface of the table, introducing external forces which complicate the experiment. With practice, you will be able to reproduce any desired collision reasonably well.

Observe the collisions carefully, and sketch the **outcomes** of all eight collisions in a clearly labeled table. In each sketch, be sure to describe the type of collision and note the relative velocities of projectile and target **after** the collisions. When a heavy projectile strikes a lighter, stationary target will the projectile ever bounce backward? Is the same true for a light projectile striking a heavy target? What is the condition required for the projectile to recoil backward from the collision? At this point you should begin to see how measurements on scattered projectile particles could tell us something about the interactions between projectile and target, and their relative masses.

For quantitative study, capture a video of a collision where both of the sliders are initially moving. **For technical reason, the initial velocity of both sliders SHOULD NOT be solely along the x or y axis of the air table. For example, having both sliders initially moving along the diagonals of the table would be fine.** Use LoggerPro to mark the position of the center of one slider in several frames before, during and after the collision. You want enough points to accurately determine the x and y velocity components both before and after the collision. After marking the first slider, step the movie back, click the icon, , to add another tracking point series, and mark the position of the second slider through the collision sequence. **Calibrate the distance scale using the white dots on the air table.** The calibration icon is . **When plotting, be sure to only plot data associated with the same slider in each graph that you print out to avoid any confusion. For any collision, you should print out two graphs, one for each slider.**

To analyze the data, select the time range on the graphs where the sliders are moving freely **before** they collide. Use Analyze > Linear Fit to get the slopes of all four $x(t)$, $y(t)$ plots. These slopes are your initial velocity components. Do the same for the interval where the sliders are moving freely **after** the collision to get the final velocity components. In fitting your data from the two sliders, **you should perform eight different linear fits**. You can now check whether or not your collision satisfies Eqs. 1, 2 and 3. To calculate the momentum of the sliders, you will need to measure the mass of the sliders with a scale. **You can find a scale at both the front and back of the lab room.** Do you find that momentum is conserved? Are the x- and y-components of the momentum constant within 20%? How about translational kinetic energy? Is it constant within 20%? If your collision seems to be significantly inelastic, where do you think the "lost" translational kinetic energy has gone?

It is also interesting to experiment with highly inelastic collisions in which the target and projectile lose a large fraction of their initial translational energy. To create a highly inelastic collision, slip one cloth collar over each of the **light sliders**, being careful that the collars do not drag on the surface. Sketch the outcome of a head-on and a near-miss collision between the two collared light sliders. **Make sure these collisions are gentle.** Is the final translational velocity roughly half the initial velocity of the projectile, as required by conservation of momentum? In the near-miss collision, where did some of the "lost" translational kinetic energy go? Complete your study by quantitatively analyzing a strongly inelastic collision. For quantitative study, capture a video of an inelastic collision where both of the sliders are initially moving. **Again, for technical reason, the initial velocity of both sliders SHOULD NOT be solely along the x or y axis of the air table. For example, having both sliders initially moving along the diagonals of the table would be fine.** Is the energy loss during the collision between the sliders with the cloth collar substantially greater than the energy loss during the collision between the bare sliders?